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Flash Suppressor Comparisons and Analysis for the F89 and M249 Machine Guns

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ARL-MR-45

February 1993

NOTICES

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 1993	Final, June 1992 - September 1992

4. TITLE AND SUBTITLE

FLASH SUPPRESSOR COMPARISONS AND ANALYSIS FOR THE F89 AND M249 MACHINE GUNS

5. FUNDING NUMBERS

PR: 1L162618AH80
WO: 62618A-00-001 AJ

6. AUTHOR(S)

DOUGLAS S. SAVICK and DAVID W. WEBB

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

US Army Research Laboratory
ATTN: AMSRL-OP-CI-B (Tech Lib)
Aberdeen Proving Ground, Maryland 21005-5066

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ARL-MR-45

11. SUPPLEMENTARY NOTES

This report supersedes BRL-IMR-975, dated September 1992.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Defense Science and Technology Organization (DSTO) reported a reduction in dispersion of 40% (single shot or burst) for the F89 light machine gun simply by changing the standard Minimi flash suppressor to a MAG 58 flash suppressor. The reduction was first observed by the troops in the field and replicated by DSTO in the laboratory. This report documents a test conducted at ARL using an M249 SAW machine gun to verify DSTO's results. The ARL study failed to show a similar dispersion reduction.

14. SUBJECT TERMS

Machine Guns; Suppressors; Dispersion; Targets; Weapons

15. NUMBER OF PAGES

19

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

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Acknowledgements

This program was made possible thanks to Mr. John Carnahan, Mr. Brendon Patton, Mr. Bill Thompson of ARL, Mr. Donald McClellan of Dynamic Science Inc., and Mr. Ken Paxton, student contractor for ARL, for their excellent efforts in instrumentation setup and operations.

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1. Introduction

The Defense Science and Technology Organization (DSTO) of Salisbury, Australia conducted experiments on the F89 light machine gun to determine target impact dispersion (TID) when using different flash suppressors on an FN Minimi gun barrel. Two such devices tested were the standard Minimi flash suppressor and the MAG 58 flash suppressor. DSTO reported a 40% reduction in TID when the MAG 58 flash suppressor was used rather than the standard flash suppressor (Wachsberger 1992). The improvement was first noticed in the field by the soldiers, then replicated in the laboratory.

The Ballistic Research Laboratory, now Army Research Laboratory (ARL), conducted a series of tests in July 1992 to determine if the U.S. Army's M249 Squad Automatic Weapon (SAW) would produce the same results with the flash suppressors as DSTO reported. The testing was conducted in the field and in the laboratory. This report will discuss BRL's evaluation of the flash suppressors and whether there is a need to pursue modifications to U.S. Army's current flash suppressor for the SAW.

2. Test Setup

Tests were performed at both an outside and indoor firing range. The M249 Squad Automatic Weapon (Figure 1) was used to test the flash suppressors. Four different configurations were tested. Each configuration was tested with five 5-round bursts. The configurations consisted of a bare muzzle, a Minimi flash suppressor for the F89, a MAG 58 flash suppressor, and the standard SAW flash suppressor (also used on the M16A2). The Minimi and MAG 58 flash suppressors both required adaptors to fit the M249. The Minimi flash suppressor adaptor was needed to convert left-handed threads into right-handed threads. The additional weight was 62 gms. The MAG 58 flash suppressor adaptor was used to adjust for the differences in diameter. The MAG 58 is a 7.62 caliber gun while the SAW is a 5.56 caliber gun. Its additional weight was 52 gms. The total weights for each suppressor are as follows: the Minimi, 107 gms; the MAG 58, 193 gms; and the standard M249, 57 gms. The flash suppressors and adaptors are shown in Figure 2.

The outside setup consisted of a paper target placed 60 m from the gun. The gun rested on the ground as the gunner fired from a pit behind it (Figure 3). The gun was supported by two methods. All configurations were first fired from a bipod with the gun's stock supported against the gunner's shoulder. The configurations were also fired from a tripod mount that provided more stability and less support from the gunner.

For the test conducted indoors, the M249 was fired from a stationary mount in order to eliminate variability due to human interaction (Figure 4). The gun was aimed at a paper target similar to the outside target. The target distance was approximately 37 m. In addition, an Oehler acoustic target was placed in front of the paper target (35 m) to record the impact locations instantaneously (Figure 5).

3. Test Procedure

The firing procedure was the same for both setups. Each flash suppressor was screwed on to the muzzle of the M249 and five 5-round bursts were fired through it. Each 5-round burst for that flash suppressor was marked on the paper targets to distinguish them from the other groups also impacting the target. After a device had five 5-round bursts fired through it, the paper target was replaced and the process was repeated with another device. Upon completion of the test, each of the five groups of each device was individually measured to determine the mean impact points and the dispersion. M855 Ball ammunition was used for the outside test and the first part of the indoor test. In order to reduce the possibility that a particular type of ammunition could have an effect on the results, the indoor test was repeated using M193 ammunition. Table 1 shows the results of all the testing.

4. Statistical Analysis of Flash Suppressor Data

The primary purpose of the statistical analysis performed on the data was to determine differences in the TID of the four types of flash suppressors. Secondarily, differences between the four types of mounts were also to be evaluated.

Three different types of TID (azimuth, elevation, and radial) were computed for each group of shots fired and each TID type was examined independently. Treating TID as the response variable, the data could be arranged into a simple two-way table (see Table 1) with columns representing mounts, rows representing flash suppressors, and with five observations recorded for each combination of mount and suppressor. Using an analysis of variance (ANOVA) and a posteriori multiple comparison procedures, differences between mounts and suppressors were evaluated simultaneously. All hypothesis tests were performed at a 5% level of significance

4.1 Azimuth TID Results No differences were noted in azimuth TID among the four flash suppressors. However, among the different mount types, the bipod firings had greater dispersion than any of the other three types.

4.2 Elevation TID Results In elevation, there was a significant difference in the TID of the flash suppressors. Dispersions using either the MAG 58 or Minimi flash suppressor were significantly lower than those obtained with the bare muzzle. Standard SAW TID fell in the middle and could not be distinguished as different from any other flash suppressor type. Among mount types, only a difference between the bipod and the stationary M855 could be detected, in which case the bipod rounds had greater dispersion.

4.3 Radial TID Results For radial measurements, again the bare muzzle system had the highest TID of any of the flash suppressors tested however it was significantly higher than only the standard SAW and the Minimi. No other pairwise differences were evident. The same mount differences in radius were noted as those observed in the azimuth data.

That is, the bipod gave the highest dispersions of any of the mounts. No differences were discernible among the remaining three mount types.

4.4 Additional Comments Because the assumption of homogeneity of variance was rejected (see Appendix), a secondary ANOVA was conducted. This "backup" analysis came to the same basic conclusions as the parametric analysis described above, with only the following minor exceptions:

- a significant difference in azimuth between bare muzzle and Minimi, and

- no difference between bare muzzle and MAG 58 in elevation.

Despite these small discrepancies, the analysis of the rank-transformed data lends credence to the overall findings of the first analysis.

A third analysis examined that subset of the data which includes the MAG 58/Minimi, and the Bipod/Tripod. The only new information garnered was of a moderately smaller reduction in azimuth dispersion with the Minimi. Otherwise, still no difference in elevation or radial dispersion could be distinguished between the two flash suppressors. Also, the bipod mount always showed a higher dispersion than the tripod.

5. Conclusions

The results from Table 1 show that the MAG 58 flash suppressor did not outperform the Minimi flash suppressor in TID for any of the four firing mount situations. In all but one case, there was no significant difference between the MAG 58 and the Minimi flash suppressors. Statistically, the same conclusion was drawn when the flash suppressors were compared for their overall performance for all four firing mount situations, as seen in Figure 6. In addition, neither the MAG 58 nor the Minimi flash suppressor outperformed the standard SAW flash suppressor. Finally, the firing mount situations were compared for their effect on TID. As expected, the bipod had a greater TID than any of the other firing mount situations.

It is not clear why the TID results did not concur with DSTO's findings. One consideration is that the gun barrel used for the flash suppressors was different (DSTO used a FN Minimi barrel, ARL used the M249 SAW). The U.S. Army Armament Research, Development and Engineering Center (ARDEC) reproduced DSTO's results by firing the flash suppressors with an FN Minimi barrel (Zisa 1992). A second consideration is that the difference in weight of the flash suppressors could have affected the gun dynamics. No conclusion could be drawn from this test but DSTO had concluded that the variation of flash suppressor weight had no effect on the their results (Wachsberger 1992). A future test is planned at ARL to determine the factor that differentiated each of the findings.

Table 1. Flash Suppressor Dispersion for Five 5-Round Bursts with Pooled Dispersion in Boldface (mils)

Device	Field Test - Bipod M855 Ammunition	Field Test - Tripod M855 Ammunition	Stationary Mount M855 Ammunition	Stationary Mount M193 Ammunition
	$\sigma_x \times \sigma_y$ (σ_r)	$\sigma_x \times \sigma_y$ (σ_r)	$\sigma_x \times \sigma_y$ (σ_r)	$\sigma_x \times \sigma_y$ (σ_r)
Standard SAW	1.27 × 1.31 (1.82)	0.74 × 0.90 (1.17)	0.97 × 0.38 (1.04)	0.83 × 1.47 (1.69)
	1.18 × 0.47 (1.27)	0.64 × 1.51 (1.64)	0.87 × 0.98 (1.31)	0.55 × 0.90 (1.06)
	1.76 × 1.53 (2.33)	1.41 × 0.80 (1.62)	0.71 × 0.77 (1.05)	0.63 × 0.63 (0.90)
	1.51 × 0.98 (1.80)	0.97 × 0.86 (1.29)	0.62 × 0.56 (0.83)	0.39 × 0.64 (0.75)
	0.81 × 0.54 (0.97)	1.03 × 0.67 (1.23)	1.37 × 0.42 (1.43)	0.65 × 0.52 (0.83)
	1.34 × 1.05 (1.71)	**0.99 × 0.99 (1.40)**	**0.94 × 0.66 (1.15)**	**0.63 × 0.90 (1.10)**
Bare Muzzle	1.23 × 0.73 (1.43)	1.32 × 2.02 (2.41)	0.94 × 0.91 (1.31)	0.77 × 0.52 (0.93)
	1.85 × 1.10 (2.15)	1.35 × 3.02 (3.31)	1.49 × 0.74 (1.67)	1.12 × 0.78 (1.37)
	1.59 × 0.99 (1.87)	1.36 × 0.91 (1.63)	1.32 × 1.02 (1.67)	0.94 × 0.90 (1.30)
	1.56 × 1.33 (2.05)	0.98 × 1.24 (1.58)	1.33 × 0.83 (1.56)	1.29 × 0.86 (1.55)
	0.96 × 0.99 (1.38)	1.42 × 1.17 (1.84)	0.23 × 0.84 (0.87)	1.13 × 1.40 (1.80)
	1.47 × 1.05 (1.81)	**1.29 × 1.83 (2.24)**	**1.16 × 0.87 (1.45)**	**1.07 × 0.94 (1.42)**
Mag 58	1.47 × 1.01 (1.78)	1.52 × 0.62 (1.64)	0.32 × 1.23 (1.27)	0.51 × 0.80 (0.95)
	1.00 × 1.02 (1.43)	0.58 × 0.59 (0.82)	1.13 × 0.57 (1.26)	1.01 × 0.42 (1.09)
	3.13 × 1.38 (3.42)	0.77 × 0.58 (0.96)	1.09 × 0.38 (1.15)	0.33 × 0.73 (0.80)
	2.87 × 1.12 (3.08)	2.60 × 0.96 (2.77)	1.01 × 0.73 (1.24)	0.60 × 1.09 (1.24)
	3.79 × 0.77 (3.87)	0.48 × 0.29 (0.56)	0.58 × 1.01 (1.16)	0.88 × 0.76 (1.16)
	2.48 × 1.07 (2.70)	**1.43 × 0.64 (1.57)**	**0.88 × 0.84 (1.22)**	**0.71 × 0.79 (1.06)**
Minimi	0.98 × 0.54 (1.12)	0.29 × 0.62 (0.69)	1.08 × 0.72 (1.30)	0.90 × 1.08 (1.40)
	0.59 × 0.68 (0.90)	0.95 × 1.05 (1.42)	0.99 × 0.65 (1.18)	0.49 × 0.35 (0.60)
	1.72 × 0.97 (1.98)	0.53 × 0.76 (0.93)	1.28 × 0.54 (1.39)	0.53 × 0.60 (0.80)
	0.90 × 1.83 (2.04)	0.73 × 0.29 (0.78)	1.39 × 0.24 (1.41)	0.74 × 0.63 (0.97)
	3.23 × 2.91 (4.35)	0.89 × 0.26 (0.93)	0.56 × 0.72 (0.91)	0.92 × 0.50 (1.04)
	1.80 × 1.67 (2.45)	**0.72 × 0.67 (0.98)**	**1.10 × 0.60 (1.25)**	**0.74 × 0.68 (1.00)**

Figure 1. U.S. Army M249 Squad Automatic Weapon

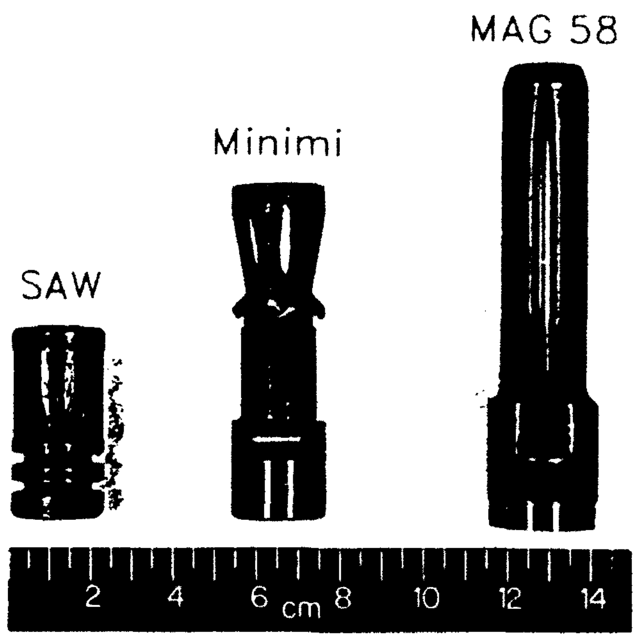

Figure 2. Flash Suppressors with Adaptors

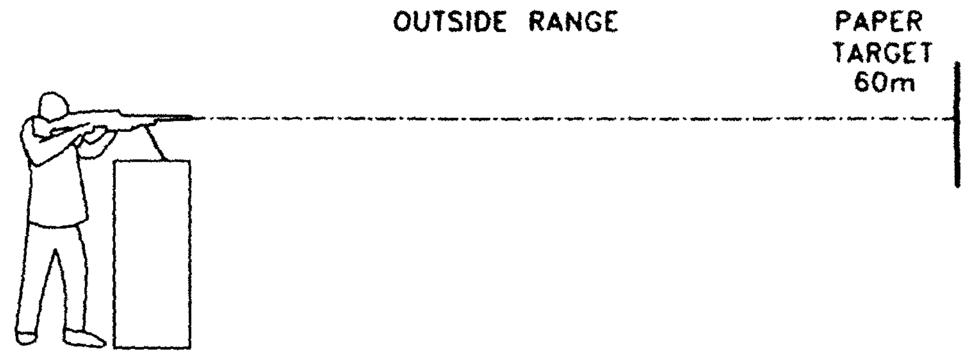

Figure 3. Schematic Drawing of Outside Setup

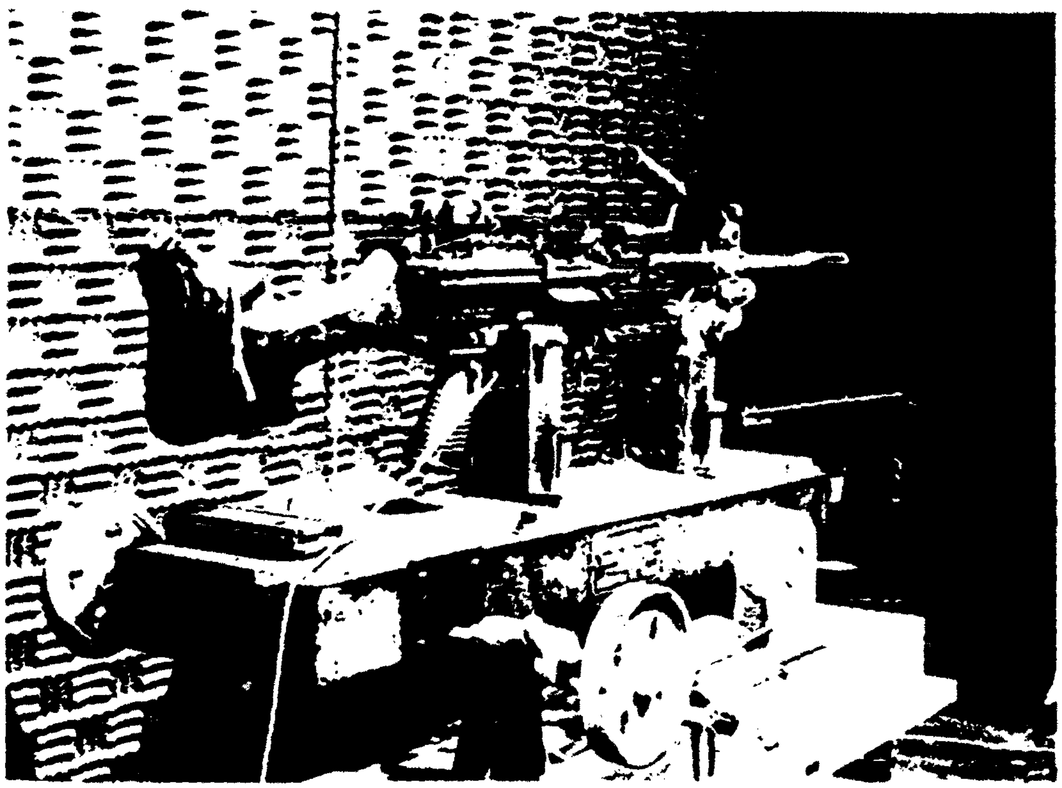

Figure 4. Photograph of Stationary Mount

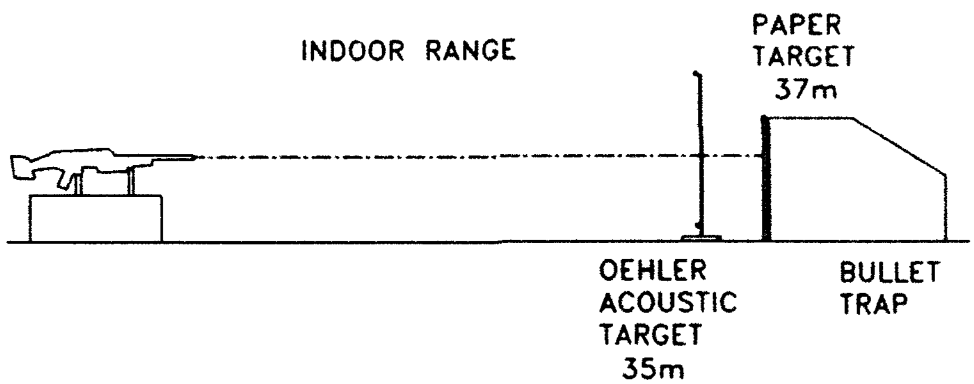

Figure 5. Schematic Drawing of Indoor Setup

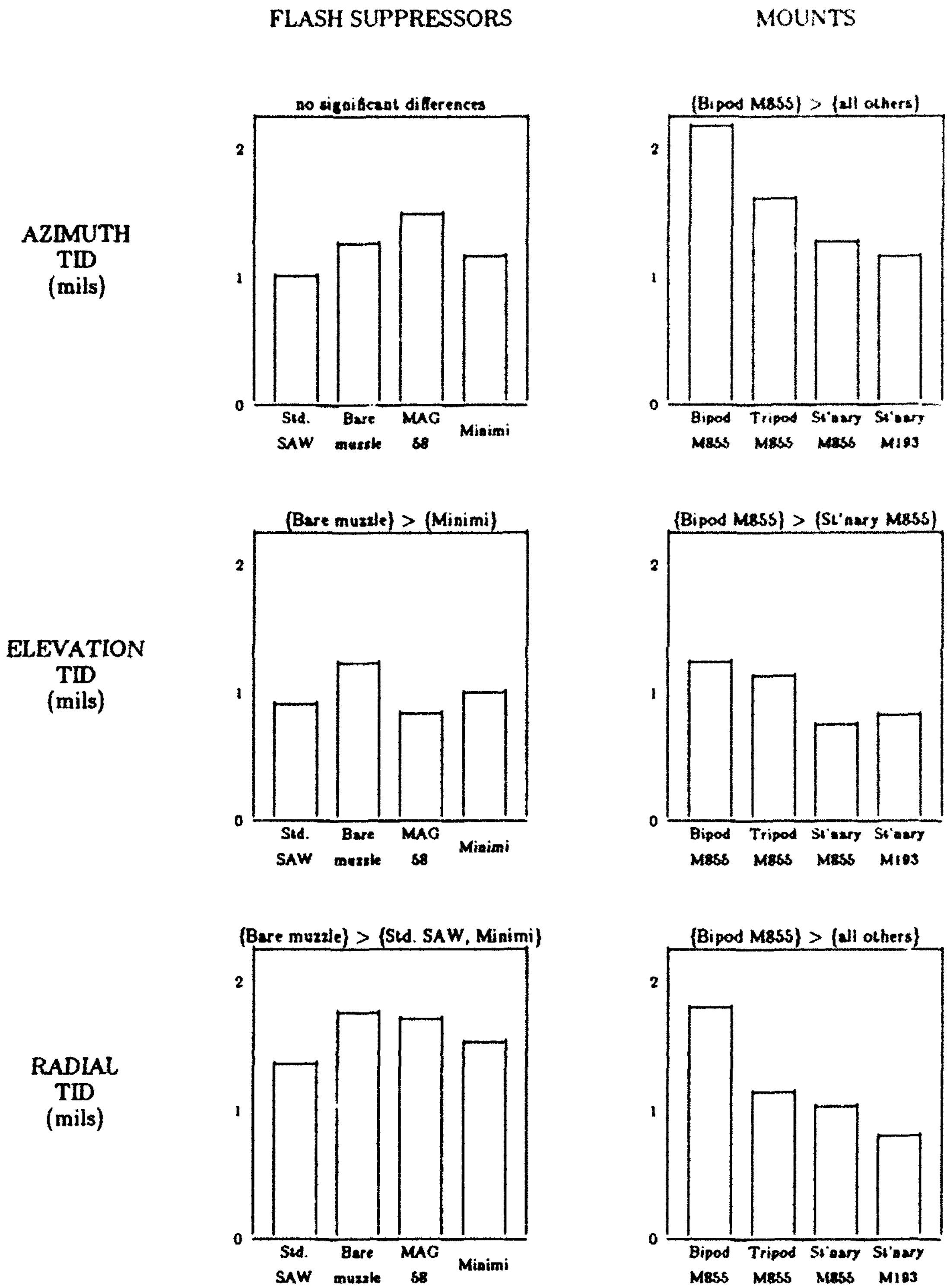

Figure 6. Summary of TID's Showing Significant Differences

6. References

Wachsberger, C., DSTO, personal communication to E.M. Schmidt, ARL-WTD, April 1992.

Zisa, T., ARDEC, personal communication to Doug Savick, ARL-WTD, September 1992.

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LIST OF SYMBOLS

σ_x	Standard deviation along horizontal axis
σ_y	Standard deviation along vertical axis
σ_r	Radial standard deviation
χ^2	Chi-square

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APPENDIX:

ANOVA

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One of the underlying assumptions behind the ANOVA is that the data are normally distributed. While this is reasonable to assume for impact locations, dispersions (which are computed as the sample standard deviation of the impact locations) are distributed as χ^2 random variables. To "normalize" a dispersion, the natural logarithm of its square is a commonly used transformation. Therefore the primary statistical analysis was performed not on the actual TID values (e.g., $\hat{\sigma}_x$), but with their log-transformed values (e.g., $\ln(\hat{\sigma}_x)$).

A second assumption required for the ANOVA is homogeneity of variance; that is, the variance of observations within each combination of mount and flash suppressor should be a constant. To test this assumption Levene's test (Milliken & Johnson 1984) was performed for each of the three responses. In each case, the test concluded that homogeneity of variance *did not* hold. However, when cell sizes are equal, as is the case with this study, ANOVA procedures are fairly robust to moderate violations of the homogeneity of variance assumption (Kirk 1982). Therefore, the analysis resumed on the transformed TID values.

The four flash suppressors and the four mounts were not selected at random from larger populations of possible suppressors and mounts. Therefore, the type of flash suppressor and the type of mount are considered fixed effects, or fixed factors. For fixed-effect experiments, the ANOVA compares the sample variance of effect means to the pooled estimate of within-cell variance. If this ratio is too large, then a difference is said to exist between the factor means.

Once a factor is found to be significant in the ANOVA, multiple comparison procedures indicate which levels of the factor differ. The particular procedure used for this analysis was a modification of Tamhane's procedure for evaluating pairwise comparisons when heterogeneity of variance and/or unequal sample sizes exist (Kirk 1982). Tamhane's critical difference for one-way fixed-effect designs with equal sample sizes reduces to

$$\Psi(\mathrm{T2}) = \mathrm{tDS}_{\frac{\alpha}{2};C,v'}\left(\frac{\hat{\sigma}_j^2+\hat{\sigma}_{j'}^2}{n}\right)^{\frac{1}{2}}$$

where $\mathrm{tDS}_{\frac{\alpha}{2};C,v'}$ is obtained from the t distribution using the Sidak multiplicative inequality, α is the experiment-wise error rate, C = p(p-1)/2 is the total number of pairwise comparisons, p is the number of factor levels, $v' = 2(\text{n-1})$, n is the number of observations per cell, and $\hat{\sigma}_j$ is the cell standard deviation. Assuming a two-way fixed-effects design with Factors A (having p levels) and B (having q levels), the modified critical difference for a_j and a'_j means is

$$\Psi(\mathrm{T2}) = \mathrm{tDS}_{\frac{\alpha}{2};C,v'}\left(\frac{\hat{\sigma}_j^2+\hat{\sigma}_{j'}^2}{qn}\right)^{\frac{1}{2}}$$

with $v' = 2(qn-1)$.

Because the assumption of homogeneity of variance failed, a supplementary analysis on rank-transformed TIDs was carried out. The rank-transformation converts the smallest of the original data values to "1", the next smallest to "2", and so on. This transformation is recommended as a backup to the parametric analysis since it has been shown to be robust to violations of the ANOVA assumptions (Conover 1980).

Appendix References

Conover, W.J., Practical Nonparametric Statistics, 2nd ed., Wiley, New York, 1980.

Kirk, R.E., Experimental Design, 2nd ed., Brooks/Cole, Monterey, 1982.

Milliken, G.A. and D.E. Johnson, Analysis of Messy Data, Vol I, Van Nostrand Reinhold, New York, 1984.

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